

NASA Space Communications R&D: Issues, Derived Benefits, and Future Directions

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Preface

In August 1986, NASA asked the Space Applications Board, through its Committee on NASA Space Communications Research, Development, and Applications, to:

- Assess policy issues affecting RD&A programs in space communications;
- Define benefits resulting from such investments; and
- If appropriate, specify requirements and directions for future research and development in space communications.

As part of the study, the committee conducted a two-day symposium to document and examine the major issues, and it reviewed technical opportunities in space communications and selected competitive technologies. Appendix A outlines the proceedings of the symposium. In addition, the committee examined international competition in telecommunications markets and considered opportunities for further U.S. government investment in space communications.

The committee members who undertook the study that produced this report and the symposium proceedings are to be commended. They gave considerable time and attention to this space communications RD&A "odyssey," more than a chairman could have asked. Without the assistance of Duncan Brown, William Michael,

David Johnson, Vicki Marrero, and Amy Janik, we would not have reached this point. On behalf of all those involved, thank you for your effort.

Robert T. Filep
Chairman

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Executive Summary

Space communication has made immense strides since ECHO was launched in 1962. It was a simple passive reflector of signals that demonstrated the concept. Today, satellites incorporating transponders, sophisticated high-gain antennas, and stabilization systems provide voice, video, and data communications to millions of people nationally and worldwide. Applications of emerging technology, typified by NASA's Advanced Communications Technology Satellite (ACTS) to be launched in 1992, will use newer portions of the frequency spectrum (the Ka-band at 30/20 GHz), along with antennas and signal-processing that could open yet new markets and services.

Government programs, directly or indirectly, have been responsible for many space communications accomplishments. They have been sponsored and funded in part by NASA and the U.S. Department of Defense since the early 1950s. The industry has grown rapidly and has achieved international preeminence under joint private and government sponsorship.

Now, however, the U.S. space communications industry—satellite manufacturers and users, launch services providers, and communications services companies—are being forced to adapt to a new environment. International competition is growing (especially in the market for launch services), and terrestrial technologies such as fiber optics are claiming markets until recently dominated by satellites. At the same time, advancing technology is opening up opportunities for

new applications and new markets in space exploration, for defense, and for commercial applications of several types.

Space communications research, development, and applications (RD&A) programs will need to adjust to all these realities. They must be better coordinated and more efficient. They must be more closely attuned to commercial markets, including the markets for both satellites and communications services, and the unique Mars and moon mission requirements. They must take advantage of RD&A results in other agencies—and in other nations.

THE NEED FOR COORDINATION AND JOINT PLANNING

This changing environment, with its emerging technological opportunities, new markets, and intensified international competition, confronts the United States with several major policy issues in space communications: What should our RD&A priorities be? How should the government agencies involved cooperate most effectively? How can federal programs best harmonize with those of the private sector?

The nation has no overall space communications policy that can offer guidance in answering these questions. Unlike most other nations, the United States has no ministry of telecommunications and no national post, telegraph, and telephone agency. Unlike our main international competitors, Japan and the European nations, we do not have a centralized space communications focus that facilitates joint government and industry planning and coordination (i.e., NASDA, ESA). Our government agencies and industrial firms involved in space communications carry out their own programs independently, with minimal coordination.

The result is that there is often too little communication between military and civilian programs and between the programs of industry and government. In addition, regulatory procedures (for example, those that determine frequency and orbital assignments, technology standards, etc.) can clash inadvertently with efforts to develop new technologies and markets. The result is duplication of effort, uncertainty, and waning U.S. competitiveness in world markets.

Two aspects of this are important. The first is a necessary government responsibility.

The government itself must develop a coherent space policy built around imaginative, widely accepted goals. Space communications should be addressed within this framework. The

nascent National Space Council might be helpful in coordinating this task, but strong leadership from the President and his NASA Administrator will be essential.

Second, the nation needs a central place in which all branches of the industry, and every government agency with major responsibilities for space communications, can discuss space communications programs. Within the framework of an overall space policy, such discussions would produce a common understanding of the technical possibilities and of future requirements for products and services. There would be fewer opportunities for conflict, greater potential for cooperation, and wiser use of resources.

There are a number of ways to achieve the desired objectives.

The Senior Interagency Group (SIG) for space, with the appropriate staff support from NASA, could carry out some of the necessary coordination. However, the SIG mechanism does not allow for participation by the private and university sectors, and it is generally used to solve short-term problems, not for long-term coordination.

A more promising approach might build upon the recently reactivated DOD/NASA Aeronautics and Astronautics Governing Board to provide leadership and resources for the establishment of a coordinating body. This board (cochaired by the Deputy Secretary of Defense and the Deputy Administrator of NASA) is intended to carry out some coordinating functions. It could be invaluable as a liaison particularly relating to classified information.

The most thoroughgoing approach would be the formation of a forum by the Executive Branch in which NASA, the Department of Defense, other agencies, the president's science and space advisors, universities, and industry could discuss space communications issues, including technological developments required to support long-term industrial and governmental needs.

The Executive Branch should encourage the formation of a forum for space communications, where government and the private sector can interact and discuss space communications issues, including policy and planning. The forum should include representatives of the satellite communications industries (both manufacturers and service providers), universities, the Department of Defense, and other agencies involved with space communications.

NASA itself could benefit from a more coherent study of the

technological possibilities, and of future requirements, not just of the agency, but of all the users of space communications, with input from the forum. Such a study could produce a "technology roadmap," relating requirements to the NASA R&D task necessary to meet them.

By performing such a study, NASA would provide documentation for review and discussion by forum participants, while simultaneously establishing an unparalleled information base on civilian and selected military technology in space communications. By forecasting trends, assessing RD&A efforts worldwide, and disseminating this information, NASA could establish a resource of reliable information for all participants in space communications.

NASA should develop a formal "technology roadmap," relating anticipated requirements of interest to NASA, other agencies, and the private sector with the RD&A required to meet them. A comparative analysis of foreign and domestic technologies would be an important element of this roadmap. The information base generated for this should be considered an important resource for all participants in the space communications enterprise.

NASA communications programs are conducted in a number of different offices, with minimal central direction or coordination. Each office has its own mission, which imposes unique requirements. However, each office should not carry out its own space communications activities without regard for the programs of the other offices. More central coordination of these programs within NASA would make better use of the available resources.

NASA should establish a focus on space communications at a high policy level in the agency to coordinate the agency's programs and to provide broad guidance for its communications responsibilities.

ISSUES FOR NATIONAL COORDINATION

More Efficient Technology and Service Development

Future R&D programs for space communications should be aimed mainly at advancing technology and service options in the most efficient manner and not at demonstrating full missions. The technology demonstrations that NASA encourages and sponsors should

concentrate on filling holes in the U.S. technology base, keeping as close to the fundamentals as possible.

In some cases, once the fundamentals are understood, NASA-sponsored flight tests may be necessary. Subsystem or component tests and demonstrations, or sometimes even computer simulations, however, could provide more efficient and economical ways to test new technology, thus shortening schedules. In cases in which flight tests are necessary, partial payloads might sometimes be launched aboard operational satellites or special demonstration platforms. Full-scale integrated flight-test packages may be warranted in certain cases.

Future NASA efforts to advance satellite technology should deemphasize single-purpose demonstration satellites, by providing a range of opportunities to test subsystems or components on NASA, DOD, and commercial satellites, on the ground, or by computer simulation, as appropriate.

Launch Services

Although U.S. industry is well along in providing commercial launch vehicles, the U.S. space communications industry (as well as other users) still lacks critically related elements of true launch services, such as liability coverage, reliably scheduled launch preparation facilities, and long-term commitments for meeting future launch requirements. With Shuttle flights no longer an option for commercial spacecraft, the private sector has no U.S. source of integrated launch services that can compete with the capabilities offered by the European Arianespace organization, for example, which has met all of the requirements for a launch services provider.

As the communications spacecraft evolve in the future, the launch vehicles and related services must evolve apace. This requires launch vehicle development plans in advance since the launch services provider will generally be selected at almost the same time as the satellite builder.

The committee urges the adoption of pertinent elements of the President's Commercial Space Initiative that would lead to provision by U.S. industry of capable, flexible, and reliable launch vehicles and services to meet the needs of government and commercial users into the 21st century. Attention to the

development of new technologies and capabilities should be an integral part of such effort.

Awareness of the Commercial Utility of Government RD&A Programs

Virtually all classes of advanced satellite communications stand to benefit in varying degrees from investments in a relatively small number of key enabling technologies. For example, the similarities between military and commercial communications satellites far outweigh the differences. Greater awareness by the DOD and NASA of the utility of their technology development and demonstration programs to the private sector and general populace should provide important opportunities for spinoffs and synergy. Conversely, better knowledge of commercially developed communications payload technology, equipment, and requirements may permit the government to decrease the development costs for its applications.

NASA and DOD, in cooperative efforts, should take the lead within the government to ensure, to the extent practical, applicability to the commercial sector when planning government-funded space communications RD&A, to include flight demonstrations.

Government RD&A programs in satellite communications too often neglect the terrestrial components of the systems, which, especially in commercial applications, dwarf the space components in total cost and ability to add value to satellite services. Greater R&D investments in terrestrial computer components would keep the level of technology high enough to deter foreign competitors and would help optimize the space communications system as a whole.

RD&A planning in space communications should recognize the importance of both space and terrestrial components of the satellite system.

THE CASE FOR GOVERNMENT INVOLVEMENT

The case for continued government involvement in commercial space communications—a profitable and growing commercial industry—has been questioned. Some see a substantial federal role as unfair or inefficient, since federal programs could compete with

private programs or services, favor one segment of the private sector over another, or produce inefficient RD&A. In addressing these questions, it is important to recognize the following considerations:

- The global communications capability provided by satellites is a strategic and economic asset. International preeminence in space communications is worth pursuing as a national goal because of the importance of the technology to both commercial and military applications.
- To foster new business sectors and economic growth, the U.S. government has traditionally made the long-term, high-risk RD&A investments needed to yield revolutionary technological advances, as in the development of new space communications systems and services. Satellite providers and satellite manufacturers seldom have the motivation to commit significant financial resources to such investments.
- Every other nation active in space communications provides government support, at least in technology development and export assistance. Coordinated planning, allocation of space communication resources and dedicated telecommunications ministries have been mentioned earlier. Private U.S. firms would be at a disadvantage in trying to compete without appropriate degrees of assistance.
- Coordination of federal space-communications-related activities and programs can maximize the benefits from the combined public and private investment and markedly improve the business climate for new space communications ventures by limiting conflicts between the aims of different agencies; eliminating redundant R&D efforts; and capitalizing on existing multiagency involvement in domestic and international policy matters (e.g., orbital and frequency assignments, availability of government launch support facilities, technology transfer, etc.).

With these considerations in mind, the committee views government involvement in space communications as desirable and appropriate. Such involvement might include the establishment of strategic goals, the encouragement of technology transfer between the government and private sectors, and the funding of selected RD&A.

NASA should continue sponsoring technology development related to civilian satellite programs; the U.S. government

should facilitate the transfer of technology between the government and private sectors and examine ways in which the government can facilitate commercial communications satellite activities.

1

Introduction

Satellite communications has made immense technological strides in its two and one-half decades of existence. ECHO, a foil and plastic balloon launched in 1962, was a passive reflector of signals that demonstrated the concept. Today, satellites incorporating transponders, sophisticated high-gain antennas, and stabilization systems provide voice, video, and data communications throughout the world. Technology now being developed will add multiple-scanning-beam antennas and automated signal-processing to make possible communications using smaller, lower powered, low-cost earth stations.

Space communications applications have been sponsored and funded by NASA and the U.S. Department of Defense since the late 1950s (Los Angeles Times, 1987; NASA Space Applications Advisory Committee, 1987; NASA Lewis Research Center, 1986). This support has been largely responsible for the rapid growth and international preeminence of the U.S. satellite communications industry. While some other space applications remain in research and development phases or in the early stages of commercialization, satellite communications has reached maturity as a commercial industry (International Resource Development, 1987; Organization for Economic Cooperation and Development, 1985; Satellite Systems Engineering, 1987; Stepp, 1987).

The most important example of NASA involvement in space

communications applications at present is the Advanced Communications Technology Satellite (ACTS) program. ACTS, scheduled for launch in 1992, will demonstrate the use of newer portions of the frequency spectrum (the Ka-band, at 30/20 GHz) and technology that permits satellites with multiple, steerable, and more directive beams and on-board signal-processing and switching, so that signals may be received at high bandwidths by large numbers of small, low-cost earth stations. Although more work needs to be done to drive down terminal costs, the technology has the potential for increased communications capacity, new markets, and new missions.

NASA also conducts a program intended to help industry create a land-mobile satellite system. The program, initiated in the late 1970s, is to culminate in the launch of an industry-sponsored commercial satellite in the early 1990s. NASA conducted much of the initial market research and the assessment of technological problems to be solved, working closely with prospective services providers. The agency developed a related joint U.S.-Canadian program, MSAT-X, to foster international cooperation on matters such as frequency allocation. NASA continues to work on developing the required terrestrial components, sponsoring regular conferences for industry and government.

Recent developments, however, have demanded reassessment of all NASA's research, development, and applications plans in space communications. Fiber optics communications has emerged as an important new technology, serving many markets previously dominated by satellites. Of equal or greater concern is the rising competition from other countries, often accompanied by strong government involvement and support (Cuccia, 1988). The United States, with no comprehensive national plan for further development of space communications technology or markets, will find it increasingly difficult to retain its preeminence, or even parity, in this environment.

At the same time, advancing satellite technology is opening up opportunities for new applications and new markets (Braham, 1988; Hampton, 1986; Miglio, 1986). Among the evolving requirements is that for new and creative adaptations of communications technology for space exploration (National Research Council, 1987). Emerging commercial applications—made possible by technology developed in programs such as ACTS and MSAT-X—include private business networks for voice and data, direct broadcast television, and a range of mobile applications, including, in the long term, personal communications.

The space missions and communications markets of the future are only beginning to be identified; the research and development to support them must be defined now. The federal government's roles in identifying the missions and applications and in defining the RD&A programs remain to be determined.

CURRENT SATELLITE APPLICATIONS

Space communications is two-way transmission of voice, data, or video signals (analog or digital) between earth and space or from spacecraft to spacecraft. All space missions, including remote sensing, space exploration, and space transportation in addition to conventional satellite communications, depend on space communications (Pierce, 1988; Posner, 1988; Profera, 1988b).

Most space communications traffic is carried by conventional communications satellites, in geostationary orbits 22,300 miles above the equator.¹ These satellites receive signals from earth and, usually without further signal-processing, radiate them back to other points on earth at different frequencies. Satellites may be used to link point-to-point, point-to-multipoint (e.g., broadcast satellites), multipoint-to-point (e.g., satellites that collect and relay data from arrays of remote sensors on earth), and multipoint-to-multipoint.

For the United States, space communications for nongovernmental purposes is employed domestically by a growing variety of commercial satellite users, including television networks, long-distance telephone companies, business communications services, and private business networks. International traffic is carried mainly by the International Telecommunications Satellite Organization (Intelsat), although there is emerging competition from private entities (PanAmSat).

Government agencies also use space communications. The U.S. Department of Defense (DOD), for example, operates extensive satellite systems for tactical and strategic communications, serving all military services and the National Command Authority (Brandon, 1988; Dickinson, 1988; Quinn, 1988); DOD uses commercial and international carriers for much of its traffic.

¹Other orbital patterns are possible. The Soviets use highly inclined, elliptical orbits with supersynchronous apogees to facilitate coverage of northern latitudes.

NASA and the National Oceanic and Atmospheric Administration (NOAA) both operate scientific and observational satellites that must communicate with earth, directly or via relay satellites. The private Earth Observation Satellite Corporation will in the future have a similar need. NASA uses the Tracking and Data Relay Satellite System (TDRSS) as its main means of data acquisition from near-earth satellites (out to about 12,000 km from earth). TDRSS, which relays transmissions through its satellites to a ground station in New Mexico, also supports the Space Shuttle and in the future will serve the Space Station (Holmes, 1987). DOD also uses satellite-to-satellite relay communications, and other nations' military authorities will soon follow suit (Quinn, 1988). Relay satellites are used mainly for governmental purposes and are likely to remain government monopolies for the foreseeable future.

NASA's space communications interests also include planetary and deep-space probes and lunar and planetary bases. Most of NASA's space communications applications, however, are and will remain point-to-point, like commercial space communications. For this reason, commercial technology development will have much in common with that required for NASA applications and many defense applications.

All these missions will benefit from current NASA and DOD technology development efforts. Programs aimed at multiple-scanning-beam antennas and automated signal-processing, for example, will increase communications capacity and permit the use of smaller, lower powered, low-cost earth stations (or lower powered amplifiers). This technology, typified by the current NASA Advanced Communications Technology Satellite (ACTS) demonstration program, will help open up new markets and missions in civilian and government communications.

THE SPACE COMMUNICATIONS MARKET

The U.S. satellite industry is big business. As Tables 1a and 1b partially illustrate, a number of U.S. manufactured satellites are currently in orbit today (35 serving North America, another 33 providing international services throughout the world, with 7 additional satellites scheduled for launch in 1988). Together, they represent an investment of more than \$6.75 billion; to this sum should be added

TABLE 1a North American Communications Satellites in Orbit March 15, 1988

Orbit Location	Satellite Name	Satellite Age (Yrs)	S/C Mfgr.	Launch Vehicle	Bandwidth MHz	#C-Band 36 MHz Equiv. Xponders	#Ku band 36 MHz Equiv. Xponders
69 W	Spacenet 2	3	RCA	Ariane	1298	36	12
72 W	Satcom 2-R	4	RCA	Delta	864	24	---
74 W	Galaxy 2	4	HAC	Delta	864	24	---
76 W	Comstar D-2/D-4	10/7	HAC	Atlas Centaur	864	24	---
81 W	RCA Ku-2	2	RCA	Shuttle	864	24	24
82 W	Satcom 4	6	RCA	Delta	864	24	---
85 W	RCA Ku-1	2	RCA	Shuttle	864	24	24
85 W	Telstar 2	3	HAC	Delta	864	24	---
87 W	Spacenet 3	0	RCA	Ariane	1298	36	---
91 W	Westar 3	8	HAC	Delta	430	12	---
91 W	SBS 4 (IBM)	2	HAC	Shuttle	430	12	12
93.5 W	Galaxy 3	3	HAC	Delta	864	24	---
95 W	SBS 3 (MCI)	5	HAC	Shuttle	430	12	12
96 W	Telstar 1	4	HAC	Delta	864	24	---
97 W	SBS 2 (MCI)	6	HAC	Delta	430	12	12
99 W	Westar 4	5	HAC	Delta	864	24	---
99 W	SBS 1 (MCI)	7	HAC	Delta	430	24	---
103 W	GSTAR 1	3	RCA	Ariane	864	24	24
104.5 W	Anik D-1 (Canada)	5	HAC	Delta	864	24	---
105 W	GSTAR 2	2	RCA	Ariane	864	24	24
107.5 W	Anik C-1 (Canada)	3	HAC	Shuttle	864	24	24
110 W	Anik C-2 (Canada)	4	HAC	Shuttle	864	24	24
113.5 W	Morelos 1 (Mex)	2	HAC	Shuttle	1298	24	12
114 W	Anik D-2 (Canada)	3	HAC	Shuttle	864	24	---
116.5 W	Morelos 2 (Mex)	2	HAC	Shuttle	1298	24	12
117.5 W	Anik C-3 (Canada)	5	HAC	Shuttle	864	24	24
120 W	Spacenet 1	4	RCA	Ariane	1298	36	12
122.5 W	Westar v	6	HAC	Delta	864	24	---
125 W	Telstar 3	2	HAC	Shuttle	864	24	---
128 W	ASC 1	2	RCA	Shuttle	1298	36	12
131 W	Satcom 3-R	6	RCA	Delta	864	24	---
134 W	Galaxy 1	4	HAC	Delta	864	24	---
139 W	Satcom 1-R	5	RCA	Delta	864	24	---
143 W	Satcom V (Alascom 1)	5	RCA	Delta	864	24	---

SOURCE: Compiled by GTE Spacenet Corporation, private communication.

the value of ground-based components of space communications systems, which dwarfs that of the satellites. Almost every component, from satellites down, will need to be replaced in the decade to come.

Communications satellites launch vehicles and services, as well as new space communications applications (such as worldwide marine and aeronautical communications, land-mobile, and interconnectivity for integrated services digital networks [Palmer, 1988]) represent other large markets, with a potential that remains to be tapped. As Chapter 3 explains, new services and new markets are being formed to meet the needs of a changing economy and to take advantage of advancing technology.

The committee conducted an informal survey of several major satellite manufacturers and operators.² The companies contacted

²The companies surveyed were RCA Astro, Hughes Aerospace, Ford Aerospace, McDonnell Douglas, Comsat, Intelsat, and GTE.

TABLE 1b Intelsat Satellites in Orbit January 1, 1988

Orbit Location	Satellite Name	Satellite Age (Yrs)	S/C Mfgr.	Launch Vehicle	Band-width MHz	Equivalent 36 MHz Xponders
307 E	VF-3	6	Ford	Atlas/Centaur	2137	37C, 21K
325.5 E	VF-4	7	Ford	Atlas/Centaur	2137	37C, 21K
332.5 E	VAF-11	3	Ford	Ariane	2250	40C, 21K
335.5 E	VAF-10	3	Ford	Ariane	2250	40C, 21K
338.5 E	IVAF-4	10	Hughes	Atlas/Centaur	800	20C
342 E	VF6(MCSC)	5	Ford	Atlas/Centaur	2137	37C, 21K
359 E	VF-2	8	Ford	Atlas/Centaur	2137	37C, 21K
60 E	VAF-12	3	Ford	Atlas/Centaur	2250	40C, 21K
63 E	VF-5(MCS)	6	Ford	Ariane	2137	37C, 21K
66 E	VF-7(MCS)	4	Ford	Atlas/Centaur	2137	37C, 21K
174 E	VF-1	7	Ford	Atlas/Centaur	2137	37C, 21K
180 E	VF-8(MCS)	4	Ford	Altas/Centaur	2137	37C, 21K

SOURCE: Compiled by GTE Spacenet Corporation, private communication.

(four manufacturers and three operators) report returns on investment ranging from 8 percent to 20 percent. Annual research and development investments by these companies range from \$5 million to \$17.8 million, and the companies say they intend to maintain these levels of R&D investment for the next several years.

A principal point of consideration for this study, then, has been the fundamental question of whether, given this commercial success, long-term government support is required, and, if so, what administrative processes would maximize the expected benefits.

THE FEDERAL ROLE IN ADVANCING COMMERCIAL SPACE COMMUNICATIONS TECHNOLOGY

With regard to the appropriate federal role in space communications, there are two fundamental issues: (1) the need for central coordination and policy and (2) the desirability of federal funding of research, development, and applications (RD&A) applicable to commercial space communications systems. In addressing both issues, the nation needs to decide what its goals in space communications are. If international preeminence is the objective, the nation will pursue a far different investment strategy than if it seeks to follow another nation's lead.

The decision will depend largely on an assessment of the national economic and strategic importance of space communications. In the past, the U.S. government has placed a rather high value on space communications as a national asset. The technology has important defense applications, in both peacetime and war; its applications in NASA's space exploration missions and in the missions of other agencies, such as the DOD and NOAA, are numerous; and the economic benefits of the industry are immense. Federal involvement in commercial space communications has been viewed as a useful adjunct to government programs, since government and commercial applications have much in common technologically.

Research, Development, and Applications

Given the existence of profitable and growing satellite manufacturers and operators, some regard any federal funding of RD&A for the commercial space communications industry as unwise. Government programs, it is argued, could compete with private sector programs, favor one element of the private sector over another, or encourage over- or underinvestment from the standpoint of society as a whole. In this view, industry, motivated by the desire for profit, should be expected to undertake the necessary work on its own. If it fails to do so, can we not simply purchase foreign communications satellites and services from foreign sources?

This argument, however, fails to recognize several important features of the space communications enterprise.

Revolutionary advances in technology, in space communications as in many other industries, require very large, very long-term investments in research, development, and application. Industry, with an eye to near-term return on investment and the degree of technical risk that may be involved, does not have the motivation to pursue long-term, high-risk R&D and tends to pursue more conservative, short-term goals. The U.S. government, unlike the private sector, has the financial resources to make these investments—which for a single test flight may total hundreds of millions of dollars—in pursuit of these advances.

Satellite services providers are especially conservative, compared with satellite manufacturers. Unlike manufacturers, who receive their revenues from discrete sales of hardware, services providers seek long-term, continuing streams of revenue from the communications services they offer. They place a high premium on reliability, are

especially averse to technological risk, and rarely pioneer risky new services.

U.S. satellite manufacturers have three main potential sources of funds for developing commercial space communications technology:

1. Government purchases of satellites carrying or incorporating advanced communications payloads may provide opportunities for technology spin-offs to commercial applications.
2. The federal government's reimbursement of certain independent research and development (IR&D) costs as overhead on government contracts may provide additional technology spin-offs to commercial applications.
3. A company may choose to invest its own profits in space communications RD&A. These investments are likely to be small, however, unless there are known commercial customers. The customers (communications services providers), as explained earlier, tend to seek low-risk technologies.

All three of these sources of RD&A funding can advance commercial technology. The advances are likely to be modest, though, because they depend on derivative gains from government programs and on limited investments of seed money. Without government involvement, there is no driving force for significant advances in commercial technology.

Policy and Coordination

A second, related, fundamental issue is the need for national coordination of U.S. government and commercial space communications programs. Most national governments regard communications infrastructure as a vital national asset and control their national communications systems through ministries of communications. Many actually operate the systems through post, telephone, and telegraph agencies.

Communications are just as vital to the United States, of course, but here it is managed by private industry, albeit under federal regulation (by the FCC and other agencies). The nation, thus far, has not established a space communications policy that can help agencies assess potential applications and technical opportunities and set priorities. NASA programs, similarly, are administered at the program level, with minimal central direction or interprogram coordination. The result, in the committee's view, is a less than optimum degree of coordination.

It should be noted, in this regard, that the government largely controls access to space. Testing and demonstration of new products and services cannot proceed without multiagency government involvement and approval. U.S. launch sites are under the control of the government. (Access to foreign sites could be difficult, especially for advanced satellites, since communications satellites are on the munitions control list and therefore subject to technology export restrictions.) Frequency and orbit assignments also are made by the U.S. government, under treaty obligations, so that new products and services requiring orbital slots and frequencies require the active endorsement of the government. (The struggle to establish land-mobile satellite service, discussed in Chapter 5, illustrates the interdependency and the importance of coordination.)

CONCLUSION

In the committee's view, U.S. preeminence in space communications is a valuable national asset, built up over decades of effort, that should not be allowed to deteriorate. The government, through NASA, has funded commercial RD&A in space communications since the first communications satellites were conceived (see Chapter 2). The ACTS program, among others, is carried out in recognition of the fact that commercial and government space communications are essentially a single enterprise, with complementary technologies. These reasons, plus the potential benefits that could be derived from the synergy among defense programs, NASA programs, and commercial programs, are, in the committee's opinion, strong justifications for a continued government role in commercial RD&A. NASA has been the agency chosen for this role in the past. It has done a credible job and has in place the necessary qualified people and requisite facilities to fulfill this function in the future.

NASA should continue sponsoring technology development on behalf of civilian satellite programs; the U.S. government should facilitate the transfer of technology between the government and private sectors and examine ways in which the government can facilitate commercial communications satellite activities.

The forms that this involvement and its management should take are major topics of this report. Several alternatives are discussed in Chapter 5.

2

NASA Involvement in Space Communications

NASA programs pioneered every major technological advance in commercial space communications, from ECHO on. RD&A programs funded by the agency have developed and demonstrated the technology and services that users of commercial communications take for granted and the capabilities to serve the applications of NASA and other civilian agencies (Dassler, 1986; Edelson, 1983; Pritchard, 1984; Young, 1983). NASA remains the most important source of funds for technology development in space communications, and the agency's applications programs tend to shape the RD&A activities of the private sector.

NASA communications RD&A programs are distributed in a number of offices, with limited central direction. In the Office of Space Science and Applications, the communications program supports developments intended for the civilian communications satellite industry and science mission communications needs for earth-orbiting or deep-space NASA missions. The Office of Aeronautics and Space Technology conducts basic research in support of NASA programs and also manages spin-offs of technology from this research. The Office of Space Operations includes developments related to TDRSS and the Deep Space Network (the core of the NASA ground network); it also operates the NASA communications network (NASCOM), which ties together the NASA ground network and the TDRSS station in White Sands with Mission Operation

Centers. The Office of Space Station performs advanced communications development in support of the Space Station.

Each NASA office has its own mission, of course, which imposes unique requirements for RD&A activities. It does not follow, however, that each office should sponsor or conduct its own space communications RD&A programs in support of that mission without regard for other offices' programs. Such a course leads to duplication of effort, since most of the underlying technologies are broadly applicable to various NASA programs. As Chapter 4 argues, more central coordination of programs, both within NASA and nationally, would make better use of scarce economic and technical resources.

Nonetheless, NASA RD&A programs have had substantial benefits for the public as well as the space communications industry. These programs, with those of the Defense Department, have made possible space communications as it exists today. There are good reasons to believe that private capital would not have been invested in the RD&A necessary to achieve these advances.

NASA'S PAST ACHIEVEMENTS IN SPACE COMMUNICATIONS TECHNOLOGY DEVELOPMENT

Soon after the success of the ECHO experiment, NASA undertook the responsibility for developing and demonstrating the technology of space communications. In the early 1960s, NASA produced the SYNCOM series, which demonstrated geosynchronous satellite service and thus provided the breakthrough for commercial satellite use.

The next major step was NASA's Applications Technology Satellite (ATS) series, seven satellites launched between 1966 and 1974. All seven satellites of the series used a single bus design, so that the cost of the bus attributable to each satellite was relatively small. The ATS series demonstrated technology, such as despun antennas, unfurlable antennas, and the use of multiple frequencies, which made possible such new services as maritime and aeronautical communications. Of equal importance was their role as platforms for demonstrating these services (Bransford, 1988). ATS-1 through ATS-5 provided a basis for incorporating frequencies and designs on such satellites as Western Union's WESTAR series. ATS-6, a sophisticated satellite in terms of design and services, not only influenced the use of L-band frequencies in the sturdy and versatile MARISATs, but also demonstrated the concepts of education, in-service training,

and hospital networks that today serve over 20 million U.S. citizens (U.S. Agency for International Development, 1975). The ATS series also contributed to U.S. foreign policy goals by making possible joint international experiments and service demonstrations; the demonstrations provided the bases for commercial systems later adopted by India and other countries (Cohen and Noll, 1988b).

Another important demonstration in the mid-1970s was the joint U.S.-Canadian Communications Technology Satellite (CTS), also known as "Hermes." CTS led to studies of the feasibility of direct-broadcast satellites (Hudson, 1986; Johnston, 1980; Parker, 1986; Smith, 1980; Thomsen, 1981). By demonstrating the use of the Ku-band (14/12 GHz), it led also to the Satellite Business System (SBS) network.

Despite this record of success, NASA programs to demonstrate commercial communications satellite technology have been controversial since the first, the SYNCOM series (Cohen and Noll, 1988b). The 1962 Communications Satellite Act, which established the Communications Satellite Corporation (Comsat) and later the International Telecommunications Satellite Corporation (Intelsat), clearly prescribed a role for NASA in R&D for commercial applications (Maletier and Hinchman, 1988). Some, however, have regarded federal demonstration projects conducted for commercial purposes as inappropriate, particularly when the industry involved is profitable and growing. In the mid-1960s, the controversy intensified as the industry expanded and matured; in the early 1970s most NASA space communications RD&A was abandoned, in the expectation that industry would take it over (Sawyer, 1987). From a 1973 peak of about \$170 million, NASA communications programs fell to about \$20 million by 1975 (Cuccia, 1988).

However, this expectation of industry takeover proved overly optimistic. For a variety of reasons, discussed in Chapter 1 of this report, the industries involved in space communications find it difficult to mount the ambitious RD&A programs that make substantial advances in technology.

NASA therefore began moving back into commercial space communications applications. In 1978, the agency began work on the key enabling technologies for the ACTS program, intended as the next major advance in satellite communications technology. This program has received significant appropriations since the fiscal 1985 NASA budget. Scheduled for launch in 1992, ACTS is intended to

provide operational demonstration in the United States of multiple-scanning-beam antenna technology, on-board switching and processing of signals, and use of Ka-band frequencies (30/20 GHz).

Another important technology development program mounted by NASA in the late 1970s is MSAT-X, a joint U.S.-Canadian program to develop land-mobile communications applications for satellites. MSAT-X has led to the recent proposal by the American Mobile Satellite Consortium to build and manage the first U.S. domestic mobile satellite system (American Mobile Satellite Consortium, 1988). In a demonstration of effective cooperation with industry, including potential services providers, NASA in 1985 announced that it was prepared to provide certain launch services in exchange for the use of capacity on the mobile satellite system for MSAT-X activities (NASA Headquarters, 1985). NASA proposed that a few dedicated satellite channels be used for advanced technology development and that NASA support and coordinate experiments by other government users. A mobile-satellite launch reservation appears on NASA's current launch manifest (NASA Headquarters, 1987).

POTENTIAL FOR THE FUTURE

There is every reason to believe that future NASA RD&A programs, like past ones, will have commercial and service benefits. While it can and does develop communications satellites and services that advance the state of the art, industry generally leaves the development of highly innovative technology—with its inherently high risks and costs—to government sponsorship. Government-sponsored programs can demonstrate new features of satellite systems, revealing the potential for new applications. Without the hundreds of successful application demonstrations carried out with the ATS series and CTS, potential users would not have discovered the benefits first hand. The products and services developed as a result of these programs have kept U.S. manufacturers competitive abroad.

The service demonstrations planned for the ACTS program should have similar impacts. Such full-scale flight tests may not always be appropriate (as explained in Chapter 5), but they do offer the singular advantage of letting users experiment over reasonable periods of time, thus raising technical confidence and stimulating the conception and development of new services and products.

The form of future NASA RD&A programs in space communications needs to be carefully thought out. As resources become scarcer,

it will be necessary to derive the maximum of benefit from these programs, at minimum cost. If NASA is to retain a role in support of commercial satellite communications applications (as this committee thinks it should), the agency will need a guiding policy, and it will need to mount strong efforts to ensure the greatest possible transfer of government technology to the private sector. Chapter 5 discusses the committee's proposals for achieving these goals.

3

Changing Conditions in the Commercial Communications Market

As recently as the early 1980s, the U.S. space communications industry was virtually unchallenged, at home and abroad. The overwhelming advantages of satellites in long-haul communications promised remarkable growth in their share of the telecommunications market. No other country was seen as a worrisome competitor. The telecommunications market, tightly regulated nationally and internationally, seemed predictable.

All of those conditions have changed substantially in the past few years. Other nations have mounted challenges in many sectors of the space communications market, most notably in the technologies and in the provision of launch services. In addition, technical developments and the deregulation of communications markets have led to competition from terrestrial communications technologies such as fiber optics, while progress in satellite technology promises to offer rapidly growing new markets for space communications.

INTERNATIONAL COMPETITION

From the inception of satellite communications, the United States has been the unquestioned leader in the development and application of the underlying technology. Today, this leadership is being contested strenuously by both the Europeans (acting both singly and as a community) and the Japanese, with other nations threatening

to pose longer term challenges (Ashford, 1987). In fact, a serious case can be made that the United States has already lost its leadership position in many technical areas and is struggling to maintain overall international parity (Sawyer, 1987; National Commission on Space, 1986; U.S. Congress Office of Technology Assessment, 1982; Washington Post, May 20, 1987).

Recent procurements of two major communication satellites (Intelsat VII and Aussat II) have seen U.S. manufacturers teamed with overseas subcontractors, either as a subcontractor or as a prime contractor with greater foreign participation than ever before. Increasingly, proposal requests from overseas demand transfer of technology and manufacturing know-how and the placement of significant portions of the programs within the host nations. This pattern further reduces the U.S. share of the market. More important, it complicates the proposed interchange of U.S. military communications technology with the civilian government agencies and companies that participate actively with overseas consortiums.

These challenges have raised concerns on grounds of national security. They also raise fundamental questions about the role of government in supporting commercial technologies.

Satellite Technology Development and Demonstration

The late 1970s saw increasing congestion of communications satellites in the geostationary orbit over the western hemisphere in C-band (6/4 GHz) and Ku-band (14/12 GHz). This congestion prompted research and development on Ka-band (30/20 GHz) satellites, not only in the United States, but also in Europe and Japan. NASA's attempt to surpass European and Japanese communications satellite technology is a major goal in the Advanced Communications Technology Satellite (ACTS), planned to be superior in several ways to its international counterparts. (Plans to flight-test ACTS were deleted from NASA budget submissions in the mid-1980s, but congressional action has restored the mission to NASA budgets each year since fiscal 1985.)

Patterns of funding for space communications shed some light on the loss of U.S. dominance. As Figure 1 shows, NASA funding of these programs reached about \$170 million (1985 dollars) in 1973, then fell rapidly, in the expectation that private organizations would support sufficient R&D in what was thought to be a mature technology. Only in recent years, with the revival of ACTS, has funding

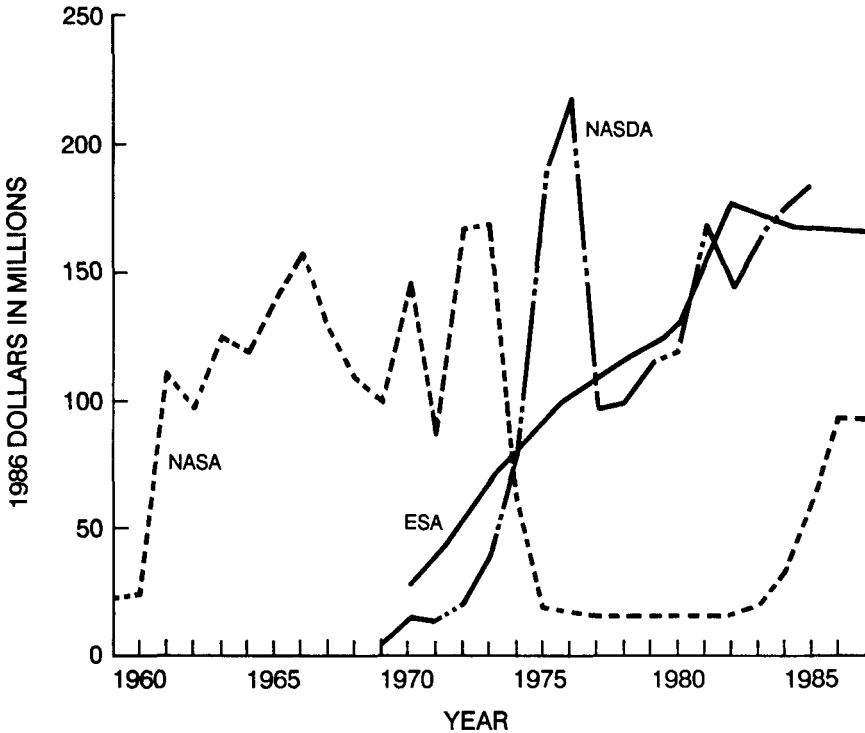


FIGURE 1 Annual Funding for Communications Programs (Cuccia, 1988).

climbed again. Meanwhile, funding of broadcast, communications, and test satellites by ESA (in Europe) and NASDA (in Japan) has continued to rise since the early 1970s. The result is that foreign government programs in space communications are today more comprehensive than those of NASA, which concentrates mostly on ACTS (AIAA, 1984; Cuccia, 1988).

Restoring the Reliability and Competitiveness of U.S. Launch Services

No analysis of the future of space communications would be complete without a discussion of launch services. With Shuttle flights no longer an option for commercial spacecraft, the private sector needs U.S. sources of launch services that can compete with the government-backed capabilities of the European Arianespace organization, for example (Sackheim et al., 1988; T. Smith, 1988). This is

applicable, of course, for other space ventures as well as for communications. The current oversupply of satellite transponder capacity is expected to fade by the early 1990s, and satellites now in orbit will need to be replaced with new, more advanced models. To meet these future requirements, satellite operators need flexible, economical launch services, and a launch services industry that can be relied on in planning for the future.

It is important to note that the need goes beyond launch vehicles. Recent activity to provide commercial launch vehicles (such as the efforts of Martin Marietta, McDonnell Douglas, General Dynamics, and others to put their rockets in commercial service) addresses only a part of the problem. The entire range of services required in placing communications satellites in orbit, from spacecraft and launch insurance to flexibly scheduled launch preparation sites, and a long-term program of development to continually match the launch capability to the satellite characteristics are needed.

Such a capability in the United States would complement foreign efforts, giving operators choices of launch organizations and encouraging healthy competition. It should be borne in mind that satellites must be cleared for export before being launched by a foreign organization. The more advanced communications technologies could present clearance problems on national security grounds.

Achieving a capability would require investments by both government and industry in launch facilities and in developing the technology of launch services and launch vehicles to match progress in satellite designs. Arianespace is a model in this respect; vehicles and facilities have developed into a system that can meet virtually any commercial launch need, and on a predictable but flexible schedule.

The problem can be traced to the mid-1970s, when the U.S. government made plans to phase out expendable launch vehicles (ELV) in favor of the Space Shuttle (known more formally as the Space Transportation System [STS]), which was intended to serve all U.S. launch needs and much of the Western world's requirements in addition. Satellite manufacturers began optimizing spacecraft features (weight, shape, stiffness, mounting and separation mechanisms, etc.) for the Shuttle (Scherer, 1988). The U.S. government and ELV manufacturers stopped investing in expendable booster technology.

This was not the case overseas, however. In Europe, the European Space Agency developed the Ariane series of expendable launch vehicles to compete, via Arianespace, head-on with the Shuttle for satellite launches worldwide. Gradually, despite some launch failures,

Ariane's order book filled as significant numbers of satellite owners could not obtain U.S. launches or were, perhaps, concerned about Shuttle launch manifest uncertainties or persuaded by the Europeans' commercial marketing approach and unwavering commitment to improved booster reliability and flexibility. Elsewhere, with less commercial fanfare, nations committed to space (e.g., USSR, PRC, Japan), whether for military, scientific, or commercial purposes, continued to invest substantially in developing ELV capabilities and capacity (Rappaport, 1988).

Thus, the Challenger disaster in January 1986 made it painfully clear that reliance on a single capable but complex vehicle for access to space was a serious error. Where once the United States dominated the Western world in ELV technology and satellite launch services, foreign competitors displaying enviable national resolve and support for their ELV programs have achieved important world positions.

The participating European countries in the Ariane ELV program are funding a continuing product development. The Soviet Union, People's Republic of China, and other nations have either begun, or have the capability to begin, offering to launch commercial satellites (Aviation Week & Space Technology, 1987). It is obvious that without an ELV alternative to the Space Shuttle, the United States cannot maintain its share of the commercial satellite launch market or, indeed, project the image of a credible space power.

There is a large backlog of commercial launch requirements that must be met during the remainder of this decade. ELV programs that can meet this demand with reliability and flexibility will receive serious consideration from commercial launch purchasers. They will consider U.S. offerings for their launch requirements, but if these are not suitable, they will seek launch opportunities offered by foreign ELV programs, some of which are specifically designed to meet commercial needs (Sackheim et al., 1988).

To be viable, a U.S. ELV program for commercial satellite launches must first meet the confidence test. The program must be supported by an entity with both the will and the means to sustain the program through the failures and setbacks that every sophisticated space program will always experience. Commercial satellite operators and users cannot depend on anything less than convincing evidence of the launch services provider's ability and commitment to deliver.

A viable ELV capability must also be able to respond to the evolving requirements of satellite operators as they develop satellite

characteristics and designs to meet the needs of their customers, often in a highly competitive market. An ELV capability with the support and funding to respond in this environment is essential. Foreign ELV providers are taking this approach today. The ELV family of Ariane I, II, III, and IV illustrates the case very well; with a choice of either two or four strap-on solid or liquid fuel boosters, the Ariane IV meets a very wide range of launch weight needs and provides fairing flexibility as well (NASA Space Applications Advisory Committee, 1987).

This condition has not been met by prior U.S. ELV policies and programs for commercial satellite launches (Van Nostrand, 1987). It is most likely to be met by U.S. industry, with the cooperation of the government, acting in recognition of the national importance and commercial viability of such a capability. Policy initiatives pertinent to the development of the capability are contained in the President's Space Policy and Commercial Initiative to Begin the Next Century (The White House, 1988).

The committee urges the adoption of pertinent elements of the President's Commercial Space Initiative that would lead to provision by U.S. industry of capable, flexible, and reliable launch vehicles and services to meet the needs of government and commercial users into the 21st century. Attention to the development of new technologies and capabilities should be an integral part of such effort.

Earth Stations

Foreign manufacturers have also proven formidable competitors in the manufacture and marketing of satellite earth stations. Japanese manufacturers have been particularly successful, with dominant positions in maritime and transportable terminals; as of September 30, 1987, for example, 41 percent of the terminals in use on the International Maritime Satellite Corporation (Inmarsat) network were of Japanese manufacture, and only 37 percent of American manufacture. Japanese companies also play major roles in the market for the traditional Intelsat terminals.

U.S. RD&A programs in satellite communications too often neglect the terrestrial components of the systems, which, especially in commercial applications, dwarf the space components in cost and ability to add value to satellite services. Greater R&D investments in terrestrial components would keep the level of technology high

enough to deter competitors and would help optimize the space communications system as a whole.

RD&A planning in space communications should recognize the importance of both space and terrestrial components of the satellite system.

NEW MARKETS FOR SATELLITES

The most important market for space communications in the past decade has been television networks, followed by long-haul telephone companies. These markets are shifting in response to advances in the technology of both satellites and terrestrial communications technologies such as fiber optics. Terrestrial technologies are capturing much of the long-haul voice business. Satellites are pioneering rapidly growing new markets in broadcast video and specialized video, voice, and data networks for business (see Chapter 4).

Fiber optics systems have proven highly successful in the long-haul point-to-point communications market. On high-density routes, in particular, optical fibers are preferred (NASA Lewis Research Center, 1986b). The reasons are fiber optics' reduced costs, quality improvements, bandwidth availability, and short propagation delay. The major disadvantage, of course, is the fixed routing.

In the United States, the major carriers and a number of minor ones have adopted fiber optics cables for most of their long-haul routes, relegating satellites largely to a position of reserve capacity. As of mid-1986, 20,000 miles of high-capacity optical cable had been installed, and another 40,000 miles were planned by 1989 (NASA Lewis Research Center, 1986b).

On international routes, Intelsat's satellite business is being partially replaced by new transatlantic and transpacific optical cables now being built by consortiums of long-distance carriers. Furthermore, AT&T, once required to divide its transatlantic business equally between satellites and cables, after 1988 will be free to choose the most cost-effective route (The Economist, 1987). In late 1987, AT&T voluntarily agreed with Comsat to continue using satellites for certain proportions of its transatlantic traffic until 1994. After that, the company could elect to use cables for all traffic on these routes.

Satellites, meanwhile, are assuming a variety of new roles, with the potential to expand their market. There are a number of evolving services for which satellites have strong advantages (Palmer, 1988).

TABLE 2 Summary Forecast of Earth Station Sales for Domestic Systems

Sales (in millions of 1987 dollars)							
Year	TT&C ^a	Broadcast Cable	Carrier Private Network	Home TVRO ^b	Telemetry	RDSS ^c / mobile	Total
1986	5	211	271	300	20	--	807
1987	5	189	351	300	22	--	867
1988	10	192	419	422	24	15	1,082
1989	15	240	529	983	26	15	1,808
1990	15	284	731	1,006	29	30	2,095
1991	15	307	898	2,009	32	45	3,306
1992	20	329	998	2,025	34	79	3,485
1993	10	305	1,136	2,061	36	61	3,609
1994	10	291	1,026	2,087	38	55	3,507
1995	5	292	1,093	2,799	40	72	4,301
1996	5	309	1,009	2,161	42	93	3,619

SOURCE: Frost & Sullivan, 1987.

^a Tracking, telemetry, and control.

^b Television, receive only.

^c Radio determination satellite service.

These services take advantage of the flexibility of satellite networks, which can be reconfigured virtually instantly, and satellites' effectiveness in serving point-to-multipoint and multipoint-to-multipoint networks (including those with mobile elements). These advantages give satellites the ability to compete successfully, for example, in video distribution markets (including direct-broadcast video), in mobile communications such as satellite newsgathering and maritime and aeronautical communications, in private business networks, and in emergency communications (Sweeney and Zimmerman, 1988).

A key to the growth of many of these applications is the use of so-called very-small-aperture terminals (VSAT) as earth stations; such terminals are increasingly widely available and at falling prices. A proprietary study (Communications Center of Clarksburg, quoted in an internal NASA report NASA Lewis Research Center, 1986b), estimated that demand for VSAT services would more than compensate for the decline in transponder demand due to the introduction of fiber optic cable. Table 2 illustrates the extent of this expected growth in terms of earth station sales for various services.

4

Satellite Applications for the 1990s and Beyond

A coherent long-range plan for space communications must be built around a comprehensive and realistic assessment of future uses. Commercial applications, and those of NASA and the Department of Defense, should be surveyed systematically with a view toward establishing RD&A programs that serve well-defined needs, maximize technology transfer among industry and government programs, and encourage private investments in R&D.

COMMERCIAL APPLICATIONS

Communications satellites have traditionally served two major commercial markets in the United States, broadcast video distribution and point-to-point voice traffic. The dominant application recently has been broadcast video, mainly for entertainment. Although the distribution channel to the user was intended to be from program sources to cable system distributors, and ultimately to the home, entrepreneurs created a direct-to-home or "backyard dish" community of users that numbers nearly 2 million today (Chase and Langereux, 1987).

A smaller, but important commercial market for communications satellites has been their use for point-to-point trunking of voice channels. This market has been eroded significantly by installation and use of fiber optic cables. Optimistic projections of filling fiber's

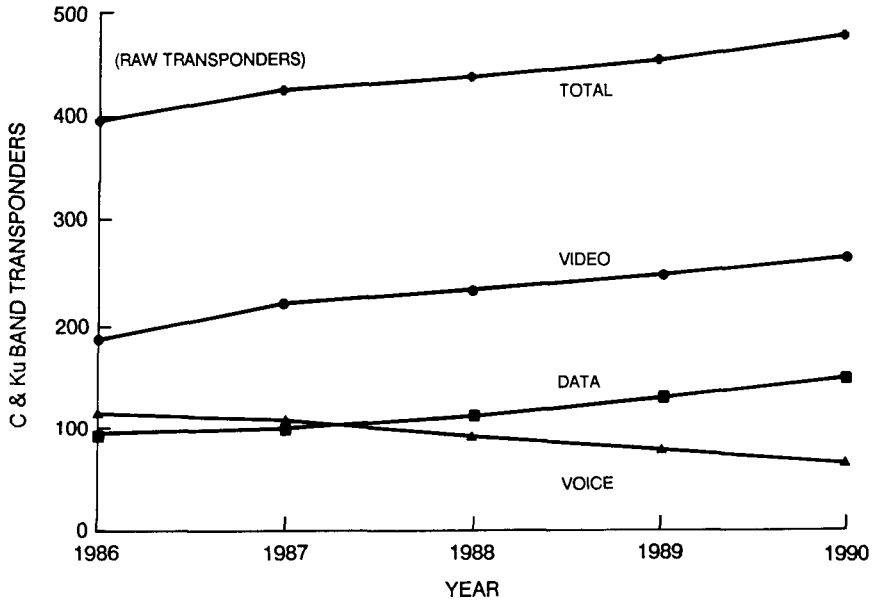


FIGURE 2 Transponder Demand Forecast (Satellite Systems Engineering, 1987).

very large bandwidth, however, may not be borne out in the near term, thus raising the actual cost per channel. Probably more important in the diminishing use of satellites for voice traffic is satellite circuits' reputation for echo, due to inadequate echo suppression technology and poor maintenance of ground equipment. In addition, many potential voice users remain reluctant to use satellite circuits because of the inherent delay caused by the distance satellite signals must traverse (Palmer, 1988).

Figure 2 shows a private projection of transponder use through 1990. The supply of transponder capacity now exceeds the demand by 30 percent to 40 percent. Demand, however, is rising and is expected to equal the current supply by 1991. Space segment revenues from domestic services, about \$700 million in 1986, are projected to exceed \$1 billion by 1989 (Frost & Sullivan, 1987).

Two recent influences have been critical in the development of new commercial applications of space communications in the United States: (1) the divestiture of the regional Bell Telephone operating companies by AT&T and (2) the advance of technology. The first of these was perhaps the more important.

The separation of the local telephone companies from AT&T's long-distance operations forced businesses that are large users of telecommunications to rely on multiple communications networks, each with its own service conditions and pricing (within the bounds of regulation). Most important, divestiture has eliminated the cross-subsidization of the costs of local services by revenues from long-distance services, and local service costs as a result have risen significantly. Divestiture thus leaves unmet the need of large telecommunications users for single vendors to take responsibility for the end-to-end services and their need for certainty about the future costs of those services. A satellite communications services vendor using earth terminals at users' premises is able to meet both these needs.

Satellites with higher power, more directive transmissions, on-board signal-processing, and the consequent development of smaller, lower cost earth stations have also been important (Ashford, 1977; Palmer, 1988). Today, a 1.8-meter-diameter earth station, costing less than a compact automobile, can provide a branch office or store with a two-way data channel to headquarters, transmitting at 56 kilobits per second; dozens of such terminals can thus be connected to a distant host computer, with a digital voice circuit to a central location, and with a capability to receive video as well.

New Data and Video Applications in Business Networks

Perhaps the most important new commercial application of satellites to arise from the two influences of divestiture and advances in technology is in data networks. Users of such networks are typically Fortune 1000 companies in the United States. The significance of this fact is that the very largest corporations are using satellites for the first time as the principal solution to their communications network needs. For example, several major retail chains will tie their stores to their headquarters, with satellite services providing interactive data exchange for credit authorization, inventory control, and other vital functions (Women's Wear Daily Technology and Operations, 1987). Other users include hotel chains, travel service companies, automobile dealerships and distributors, health care providers, banks, and financial service organizations.

A critical issue in the use of satellite networks for these major commercial users is the ability to integrate multiple functions in a single network. Many of the early adopters of satellite networks

based their initial decisions mainly on the economics of data-related needs. However, once a satellite network is chosen, the additional advantages of satellites become apparent: connectivity to any location in the satellite's coverage area with virtually equal ease and cost and access to the full capacity of the satellite (removing the bandwidth limitations inherent in the channel assignment of the long-distance network and in the copper connections of telephone local loops). Once the initial equipment is in place and the initial application economically justified over other alternatives, it is very inexpensive to provide interactive high-speed data exchange; receive-only video for training, education, and entertainment; and voice channels to all nodes of a broadly distributed corporate network.

In the longer term, as satellite data and video networks begin to be widely installed, connectivity may be established among several satellite networks serving different levels of vertical markets. For example, a retail chain can be connected directly into the networks of wholesalers, financial institutions, and shippers, fully integrating the communications process.

Other New Video Applications

In addition to the new applications of television in the business networks just described, other new uses are being found for satellite-distributed television. In entertainment video, pay-per-view movies are now delivered by satellite, both through cable head-ends and directly to receive-only backyard terminals.

Perhaps more interesting, however, are new education and training applications. Many companies and organizations have established networks to deliver educational video to schools or office buildings. The Texas Interactive Instructional Network transmits accredited instruction in such subjects as foreign languages, math, and sciences to high schools in several states. The National Technological University (NTU) enables graduate students in engineering and computer sciences to obtain master's degrees at their work sites while holding full-time jobs; the NTU delivers classes from two dozen universities directly to students' places of employment (National Technological University, 1987). The Hospital Satellite Network provides professional training for medical personnel at more than 700 hospitals. The Public Broadcasting System's National Narrowcast Service offers business training videos that are transmitted directly to inexpensive terminals at employers' offices. These one-way video services are

generally integrated with two-way voice or computer conferencing systems to permit communication between teachers and students.

Another business video application, which has developed more slowly than many predicted but continues to grow, is interactive video conferencing. The acceptance of business television by a broad community may eventually be the stimulus this application needs to achieve its full potential as a satellite-provided communication service. Technological advances that offer more user-friendly features (including high-definition video) and lower initial and operating costs have helped this application grow.

As mentioned earlier, the many backyard dishes receiving television today offer a potentially lower cost means of directly reaching the mass consumer market. This so-called direct-broadcast satellite (DBS) video seems to have tremendous potential (especially if high-definition capability is included), but has yet to be offered commercially. A number of prospective DBS operators have decided not to go forward, but there are still several companies authorized to do so. However, the extremely large start-up costs of launching high-powered DBS satellites and the availability of other means of delivering video electronically or physically to consumers' homes make DBS strictly for entertainment video an extremely risky venture. Perhaps greater effort spent in developing DBS and high-definition video standards will facilitate credible evolution of the technology's applications. Also, programming sources and costs clearly require attention. A longer term possibility for DBS in the direct-to-home market may be found by combining video and data applications, as the costs of small terminals are driven down by market growth.

Voice Applications

Several new voice applications of satellites have begun to emerge. One of these is the integration of digital voice service into star-topology corporate networks (with many points communicating with central hub), connecting headquarters to remote offices with voice service as an adjunct to a data network having the same topology. Another voice service becoming more important is the use of satellites for quickly reestablishing communications on an emergency basis when major fiber, wire, or terrestrial microwave routes fail.

Transportable and Mobile Terminal Applications

Transportable terminals have been used in commercial satellite

services for some time. An emerging application that has become important to television broadcasters and networks is satellite news-gathering. The use of truck-mounted or crated satellite terminals to quickly reach the sources of breaking news events is growing rapidly. Within minutes of its arrival, a crew can be feeding live television to network or station news directors via satellite. There is really no alternative to satellites in thus achieving wide-bandwidth connectivity (for video signals) quickly to virtually any location.

Mobile satellite services (MSS) with multiple access are receiving increasing attention for commercial applications. Both land-mobile and aeronautical-mobile services are being considered by several organizations (e.g., Geostar, Omnet, American Mobile Satellite Corporation to provide MSS in the United States and Telesat for Canada). Aeronautical services could be used, for example, to save fuel in transoceanic flights by integrating satellite navigation and communications systems. They could also bring additional communications capabilities to passengers. It is a little early to predict the development of these markets, but they may become important in the future. Almost certainly, there will be an interest in connecting some of these mobile users into other business satellite networks described earlier. The connectivity advantages that satellites provide over all other alternative communication means will be an important factor in the development of all of these new applications (Rosen, 1988).

Further downstream in time is the intriguing possibility of satellite-based personal communications. In this application, communications would be extended to the personal level utilizing low-cost, hand-held terminals, ultimately offering instant global person-to-person access.

NASA APPLICATIONS

NASA's space communications needs, of course, depend on the agency's future missions. The lead time for developing systems to serve these needs is about a decade. In discussing NASA applications of space communications, therefore, it is useful to look at NASA's projected missions for the next several decades.

One important study of these missions was made by the National Commission on Space (1986). Taking a 50-year view, the commission recommended a three-part program with the following goals:

- Advance understanding of the planet Earth, its solar system, and the Universe.
- Explore, prospect, and settle the solar system.
- Stimulate space enterprises for the direct benefit of the people on Earth.

Such a program would entail a variety of manned and unmanned missions, at distances ranging from low-earth orbit to deep space. Digital voice, data, and video communications would be needed for transmitting and relaying scientific data from earth-observation satellites and spacecraft and for communications between spacecraft.

The complexity of many of these systems would be very great. For example, the Space Station will need to communicate with polar and co-orbiting platforms, with crew members performing extra-vehicular activities, with teleoperated utility and service platforms, with in- and outbound transfer vehicles (both manned and unmanned), with Earth, and eventually with other stations farther from Earth, such as on the Moon or in geostationary orbit. A preliminary design by the Harris Corporation provides more than 60 communication links, using 30 antennas. (NASA Lewis Research Center, 1986a). A manned moon or planetary base would have even more sophisticated requirements.

This variety of missions will require increasing capabilities, according to the NASA Lewis report. For example, deep-space probes envisioned in the future will expose the on-board communications equipment to ever harsher operational environments, such as high radiation (in the Galileo mission) and impact (in comet rendezvous and asteroid exploration missions).

Such missions will also continue to place a premium on low-noise, low-mass, power-efficient microwave and electronic components. One critical need cited by NASA Lewis is for power amplifier devices with efficiencies greater than 50 percent and power levels higher than 50 watts at X- and K-bands. The Lewis Center is developing a traveling wave tube that exceeds 55 percent efficiency at 20 watts in the X-band and has demonstrated in the laboratory a 48-watt traveling wave tube with 50-percent efficiency at the Ka-band.

The likely interconnectivity requirements deriving from consideration of the space station, platforms, data relay satellites, and manned bases on the Moon or Mars also have numerous technology development implications. Large, high-gain, small-beamwidth, fixed and multiple-scanning-beam antennas, on-board processing and routing, and intersatellite links at both optical and RF frequencies

would be required. Achieving these capabilities will require continued investments in such key building-block technologies as large unfurlable antennas, improved on-board beam-forming networks, high-capacity switches, low-noise receivers, higher efficiency modulators and demodulators, encoders and decoders, programmable frequency shifters, and a variety of optical communications components.

Finally, a variety of key supporting technologies, inherent in the critical building-block technologies noted above, offer opportunities for reductions in weight and power requirements and are therefore worthy of sustained investment. Examples include device process developments (in such technologies as complementary metal oxide semiconductors—silicon on sapphire [CMOS-SOS] and gallium arsenide [GaAs] devices), discrete GaAs power amplifiers and receivers, monolithic microwave integrated circuit (MMIC) and very-large-scale integrated circuit (VLSIC) components, advanced materials, radiation hardening (for longer life in space), and optical communications components.

It is worth noting that much of the space communications technology R&D needed by NASA for its own systems can be applied in whole or in part to many of the expected commercial satellite communications systems. (See, for example, Palmer, 1988).

MILITARY APPLICATIONS

Military satellite systems are beyond the scope of this report, except insofar as they may offer technology that could be transferred to civilian systems. The Department of Defense, with a satellite program in many ways parallel to civilian programs, would seem to have much to offer on this score.

Over the past decade, satellites have come to dominate the Department of Defense's primary systems for command and control. Current capabilities include a mix of five Defense Satellite Communications Satellites (DSCS II and DSCS III) in orbit, with additional satellites for nuclear and conventional command and control. FLEETSAT and LEASESAT satellites provide primary service at ultrahigh frequency (UHF) to mobile terminals with small antenna apertures (and correspondingly low data rates and jam-resistance). The DSCS II and DSCS III satellites operate at superhigh frequencies (SHF, under 10 GHz) and provide higher throughput capabilities to large fixed and transportable earth terminals. The DSCS III employs flexible multibeam antennas that can be reconfigured by ground

command. The DSCS III also is capable of detecting and locating jammers, and rejecting jamming signals by antenna pattern nulling. The MILSTAR program is designed to operate at extremely high frequencies (EHF, above 20 GHz) with even higher jam resistance at moderate data throughput rates (Dickinson, 1988; Quinn, 1988; Robinson, 1988b).

R&D in military satellite communications concentrates on greater capacity under adverse conditions, higher resistance to jamming, improved survivability, and increased connectivity. The leading development program at present is MILSTAR, intended to provide survivable global communications, with active-aperture antennas, high-speed modulators, transmitters of high power and high efficiency, and high-speed hardened switches. The Strategic Defense Initiative has its own program to define communications needs for command and control. In fiscal 1987, DOD space communications R&D funding was \$517 million (Dickinson, 1988).

Military satellite communications applications have much in common with civilian applications, and there are a number of military developments with potential civilian spinoffs (Dickinson, 1988). These developments include low-noise amplifiers, radiation-hardened integrated circuits, improved traveling wave tubes and solid state amplifiers, various antenna technologies, encryption and data processing techniques, very-high-speed integrated circuits, and on-board signal-processing methods. In addition, Dickinson noted that DOD launch vehicle programs should improve the national launch capacity, to the benefit of both military and civilian users.

Classification restrictions have constrained the transfer of technology from defense R&D to civilian programs. However, civilian programs have outpaced defense work in applying the technology of solid-state power amplification. Civilian programs have benefited from military R&D in spacecraft antenna technology (including beam-shaping and unfurlable reflectors) and linear amplification, especially in low-noise pre-amplifiers.

Much of the spillover from defense to civilian programs occurs through the satellite system and subsystem manufacturers, which develop components and subsystems for military missions and then apply or extend the technology to civilian missions. There is no formal program for this technology transfer, and it is difficult to document. Nonetheless, most would agree it is widespread.

Managing Research, Development, and Applications in Space Communications

A changing environment for space communications, with emerging technological opportunities, new space missions, new markets, and intensified competition, confronts the nation with several major policy issues: What should be the RD&A priorities? How should the government agencies involved cooperate most effectively? What is the proper relation of government with this industry? How can federal programs best be harmonized with those of the private sector?

To answer these questions, the nation needs a shared sense of its goals for space communications and how those goals are to be achieved. One agency must not impede the work of another. Industry must have a clear idea of the aims of government RD&A programs. Government must have a clear idea of what industry needs.

Today, however, goals are obscure, and activities are in some respects inconsistent. The failure of coordination within the federal government results in substantial waste. Land-mobile space communications provides an excellent example of the costs of such a failure to establish overall policy guidance. The U.S. government in 1987 took exception to a World Administrative Radio Conference (1987) decision allocating frequencies between land-mobile and aeronautical services. The resulting prospect of two different standards, for domestic and international services, retarded the development of the industry by creating uncertainty among potential manufacturers and services providers in the United States.

The Federal Communications Commission decision to force a specific market and business structure on U.S. land-mobile services providers had a similar effect. The FCC required the earliest license applicants, in the early 1980s, to wait while an inquiry was opened to identify other potential entrants, a number of whom stepped forward. NASA at this point entered the matter, announcing that only two satellites would fit in the assigned frequency band; the FCC therefore required the formation of a consortium. Ultimately, an eight-company consortium was formed, incorporated as the American Mobile Satellite Consortium, to provide services on a wholesale basis. As of mid-1988, no land-mobile satellite services were being offered in the United States.

Thus, overlapping uncertainties about frequency allocations, regulatory goals, and international cooperation are likely to lead to a slowing of U.S. industry's entry into this market, despite NASA's steady efforts to work with industry to develop the appropriate technology. No other nation with a major role in space communications seems to have such problems. Most nations have ministries of telecommunications, and often national post, telephone, and telegraph agencies, to ensure that policy is consistent and priorities clear.

Coordination is lacking not only nationally, but within NASA itself. NASA communications RD&A programs, as explained earlier, are distributed in a number of offices, with very little central direction or oversight. Programs in NASA and DOD sometimes duplicate each other. The result is inefficiency, contributing to waning competitiveness in world markets.

For the United States, the years of unquestioned preeminence are past. Efforts will need to be more efficient, and far better coordinated, if we desire to be competitive in the future.

TOWARD BETTER COORDINATION OF SPACE COMMUNICATIONS

There has been much recent discussion of space policy coordination. The idea of a national space council in the White House, with general coordinating functions, has been endorsed by the National Commission on Space (1986), among others.

The United States may not need a formal space communications policy, although the development of such a policy would have its

advantages. At a minimum, though, there are two important aspects to be considered. The first is a necessary government responsibility.

The government itself must develop a coherent space policy built around imaginative, widely accepted goals. Space communications should be addressed within this framework. The nascent National Space Council might be helpful in coordinating this task, but strong leadership from the President and his NASA Administrator will be essential.

Second, the nation needs a central place in which all branches of the industry, and every government agency with major responsibilities for space communications, can discuss space communications programs. Within the framework of an overall space policy, such discussions would produce a common understanding of the technical possibilities and of future requirements for products and services. There would be fewer opportunities for conflict, greater potential for cooperation, and wiser use of resources.

There are a number of ways to achieve the desired objectives. The Senior Interagency Group (SIG) for space, with appropriate staff support from NASA, could carry out some of the necessary coordination. However, the SIG mechanism does not allow for representation by the private sector. SIGs also do not generally carry out long-term coordination; they are used instead to solve short-term problems.

A more promising vehicle might be the DOD/NASA interagency Aeronautics and Astronautics Governing Board, which is being reactivated. This board (cochaired by the deputy secretary of defense and the deputy administrator of NASA) is intended to carry out some of the coordinating functions envisioned here. It could, in fact, serve as the nucleus of a coordinating body, with particular responsibility for the control of classified information.

The most thoroughgoing approach would be the formation of a forum by the Executive Branch in which NASA, the Department of Defense, other agencies, the president's science and space advisors, universities, and industry could discuss space communications issues, including technological developments required to support long-term industrial and governmental needs.

The Executive Branch should encourage the formation of a forum for space communications, where government and the private sector can interact and discuss space communications issues, including policy and planning. The forum should

include representatives of the satellite industries (both manufacturers and service providers), universities, NASA, the Department of Defense, and other agencies involved with space communications.

ESTABLISHING A LONG-TERM TECHNICAL FOCUS

Virtually all classes of advanced satellite communications applications stand to benefit in varying degrees from investments in a relatively small number of key enabling technologies. The specific requirements associated with each advanced mission should be assessed to identify opportunities for sharing benefits between programs. Care must be taken not to unduly compromise an individual mission's requirements by increasing the range of technology applications, but multiple program benefits should be considered in developing the technology development plan.

Similarities exist between near-earth communications satellites and the communication capabilities of deep-space probes, with attendant potential mutual benefit from appropriately coordinated RD&A (Posner, 1988). Military and civilian satellite communications programs, as explained earlier, also have similarities that would benefit from greater sharing of technology.

The Need for a Technology Roadmap

A critical element of any future plan for NASA's civil space communications RD&A must be a "technology roadmap," defining the current status and objectives in each technical area relevant to various missions and applications. Such a roadmap can be used to pinpoint technology gaps or shortfalls, identify areas of commonality or overlap (where one R&D project can benefit multiple missions), assess international competitiveness, and suggest opportunities for international cooperation. The roadmap is essential for funding, scheduling, establishing priorities, and allocating human and other resources.

A recent report from the NASA Lewis Research Center is a good example of a technology roadmap (NASA Lewis Research Center, 1986b). The authors identify enabling and beneficial technologies for a variety of satellite communications applications, ranging from small terminals to mobile, lunar, and planetary communications (see Table 3). The report also provides the authors' views on the state of

TABLE 3 Lewis Research Center Mission Supported Technology

TECHNOLOGIES	MISSIONS						
	1	2	3	4	5	6	7
ANTENNA SYSTEMS							
MICROWAVE MONOLITHIC INTEGRATED CIRCUIT ANTENNAS	●		●		●	●	
PRECISION REFLECTOR			●		●		
MOBILE TRACKING ANTENNA					●		
DIGITAL SYSTEMS							
SWITCHING & PROCESSING SUBSYSTEMS							
FAULT TOLERANT BASEBAND PROCESSOR	●				●	●	
MATRIX SWITCH		●	●				
ON BOARD MASTER CONTROL		●	●			●	
COST EFFICIENT GROUND TERMINAL	●		●				
SIGNAL PROCESSING COMPONENTS							
AMTD MODEMS	●	●	●			●	
ADAPTABLE MODEM	●		●				●
MULTI-CHANNEL DEMODULATOR	●				●	●	●
HIGH SPEED CODEC	●		●				
RADIO FREQUENCY SYSTEMS							
HIGH POWER, HI-EFFICIENCY TRANSMITTER (S/C)		●			●	●	●
LOW POWER, SS TRANSMITTER (S/C)		●					●
GROUND TERMINAL RECEIVE SYSTEM	●		●		●	●	●
SS UPLINK TRANSMITTER	●		●		●	●	●
SYSTEM INTEGRATION TEST & EVALUATION							
GROUND TEST & EVALUATION	●	●	●	●	●	●	●
FLIGHT VERIFICATION	●	●	●	●	●	●	●
ADVANCED STUDIES							
SYSTEM DEFINITION & ANALYSIS	●	●	●	●	●	●	●

NOTE: ● = relevant; ○ = highly relevant.

the art for these technologies, what advances are being sought, and what industry may contribute.

The development and maintenance of the resulting roadmap will require an ambitious program of identifying, collecting, and providing information. Both military and civilian domestic technology will need to be monitored and assessed, along with foreign technology. Information will need to be distributed as widely as possible, within limits set by the need to protect classified information. NASA, because of its broad programs in space communications and its contacts with the industry, is well suited to the task of managing this information base and conducting its associated technology assessments, forecasts, and analyses. This information base would become an important resource for all participants in the space communications enterprise.

NASA could benefit from a coherent study of the technological possibilities and future requirements, not just of NASA, but of all

users of space communications, and from relating the requirements to the NASA RD&A tasks necessary to meet them.

NASA should develop a formal "technology roadmap," relating anticipated requirements of interest to NASA, other agencies, and the private sector with the RD&A required to meet them. A comparison of foreign and domestic technologies would be an important element of this roadmap. The information base generated for this should be considered an important resource for all participants in the space communications enterprise.

As implied above, one benefit of improved coordination of space communications programs nationally, and more central management of NASA programs, would be more efficient use of RD&A resources. At present, with each NASA office operating its own, largely self-sufficient, technology programs, resources are not used effectively. Coordination across NASA offices with space communication interests is a critical part of the space communications enterprise whether research, development, applications, or operations. Insufficient communication between civilian and military programs further increases the potential for inefficiency.

NASA should establish a focus on space communications at a high policy level in the agency to coordinate the agency's programs and to provide broad guidance for its communications responsibilities.

RD&A Priorities

The first priority in a long-range RD&A plan should be on fundamental studies whose results are expected to be broadly applicable to multiple missions of NASA, DOD, or industry. Such studies can lead to major advances in technology and ultimately new mission capabilities. The goal should be to fill holes in the U.S. technology base. Table 4 illustrates the broad applicability of several NASA technology programs.

In some cases, once the fundamentals of a technology are understood, NASA may find it appropriate to develop the technology further. After thorough performance analysis, the technology will often require testing. Several options present themselves at this stage.

TABLE 4 Major Application of Technologies to Other Missions

Technologies of Next-Generation Switching Satellites	Technologies Key to Other Missions					Commercial (Advanced Switching Satellite)
	Commercial (Advanced Mobilsat)	Growth Space Station	Advanced TDRS	Other (e.g., Science)	Military	
Phased array						
o Large aperture	x	-	-	x	TBD	x
o Phased array	TBD	x	x	TBD	x	x
o MMIC	-		x	x	x	x
o Many simultaneous beams	x	x	x	TBD	x	x
On-board processing						
o VLSSI/VHSIC processing	x	x	x	x	x	x
o Photonics	x	x	x	x	x	x
o Advanced software	x	x	x	x	x	x
Intersatellite links	x	x	x	x	x	x
Advanced network control	x	x	x	x	x	x
Other	x	x	x	x	x	x

SOURCE: Braham, 1988.

A NASA-funded flight test to demonstrate a new mission may be necessary. Often, however, subsystem or component tests, on the ground or in space, may be sufficient. Sometimes computer simulation will be appropriate.

In other words, wherever possible, the least costly and time-consuming option that will accomplish the desired goal should be chosen. An experiment or flight test that can be done in low-earth orbit—for example, on the planned Space Station—should not be conducted in geostationary earth orbit. Table 5 enumerates some of the advantages of this approach. A full mission demonstration should not be conducted unless the mission itself is of primary importance and the demonstration justifies the expense and the time involved.

Future NASA efforts to advance satellite technology should deemphasize single-purpose demonstration satellites, by providing a range of opportunities to test subsystems or components on NASA, DOD, and commercial satellites, on the ground, or by computer simulation, as appropriate.

Sometimes a flight test can be made with a partial payload aboard a special experimental spacecraft. Other options may be "piggy-back" tests of components as additions to operational commercial or government satellites. NASA could encourage such tests in a number of ways, such as by indemnifying spacecraft owners

TABLE 5 GEO vs. LEO Comparison

Desired Feature	Flight Demonstration Programs (GEO)	Technology Program on Station (LEO) ^{a, b}
Develop fly broad range of individual technology advancements on timely basis	No; one large program every 10 to 12 years	Yes; many frequent separate technology programs
Fully utilize space station benefits (e.g., manned test facilities, continuous availability, low booster cost)	No	Yes
Technology applicable to multiple programs: growth space station; other NASA (e.g., scientific and advanced TDRS); commercial comsats; military	Limited in timeliness and scope	Yes
Maximum funds used for commercial technology	<<100% (rest for, boosters, mission demo,	Almost 100% integration)
Can afford greater risks (and rewards) in any technology	No; all technologies serially linked in one system demonstration	Yes. Many parallel technology programs; one failure not catastrophic
Constant yearly funding (Congress prefers)	No; peaks/valleys	Yes
Eliminate need (and risk) to predict one best commercial operational system 15 years hence	No	Yes
Broadest industrial participation in major projects	No	Yes

^aPartial payloads, if implemented, would provide similar benefits at GEO.

^bThere are some features that can mitigate against employing LEO, however: e.g., limited test time per orbit and a potentially complicated RFI environment.

SOURCE: Braham, 1988.

against losses incurred, by waiving certain frequency restrictions, by subsidizing test opportunities aboard the Shuttle, or simply by identifying operational satellites with the potential for serving as test platforms. These possibilities should be systematically explored.

Supporting the fundamentals tends, in most cases, to support all NASA communications responsibilities, including commercial communications satellites, near-earth and space station communications, and deep-space communications. Satellite prime contractors as well as subsystem providers all benefit. Government-sponsored test activities should be made known and results made available to appropriate DOD and other government agencies.

The approach recommended here should permit frequent and timely launches each year of the latest technology. If so, the desired results can typically be achieved at either low-earth orbit or geostationary orbit, with the former often preferable, as argued by Table 5. The Space Station, in particular, would permit orbital manned operations, including assembly and test, payload upgrading or repair, and return to Earth as needed. The Shuttle Space Transportation System (STS) should also be considered if short-duration investigations are involved. The selection of a test orbit for a specific program should be carefully assessed by a technical working group.

Such a program, under NASA leadership, would lead to more numerous launch opportunities for development and evaluation. It would be endorsed nearly unanimously by the commercial communications satellite industry, including the prime spacecraft builders and the new subsystem providers that the more numerous technology demonstration opportunities would encourage. The technology development program, ground station providers, and existing and potential users in the private and public sectors would all benefit.

The costs and risk to the government would be low to moderate (no more than present costs), and the lead time for technology and market development could be cut from about eight years (for large demonstration spacecraft projects such as ACTS) to maybe two to three years for the demonstration packages. DOD would benefit from a healthier and more widespread civilian space communications technology base. Benefits would also be felt in our balance of payments, our national prestige, and the importance of our commercial communications satellite exports to our international political and strategic goals. NASA could play a seminal role in these developments.

Involving the Private Sector in NASA RD&A Programs

If the federal government is to undertake funding and direction of commercial R&D, it must obtain the active participation of the

industries involved. Particularly important in this process is the community of users of space technology.

Private sector efforts could be guided more effectively. Some space communications RD&A is performed by industry, which regards NASA funds as "seed money," reflecting the priorities placed by the government on various technologies. Companies are often willing to invest discretionary funds, in the form of profit or independent research and development (IR&D) dollars in complementary efforts to achieve the desired technical results sooner or better. While companies do this to gain competitive advantage, much of their proprietary work finds its way into the public domain, thus enhancing the national technical capability. Considerable technical interaction and information exchange takes place among individuals and organizations in NASA centers and the U.S. spacecraft industry.

Unfortunately, participation in the process by the users is inadequate. Satellite operators, services suppliers, and users have vital contributions to make to the development of RD&A policy. Their point of view could focus government RD&A activity more sharply on actual requirements, making the resulting technology more flexible, more reliable, and more useful.

For example, government RD&A programs in satellite communications too often neglect the terrestrial components of the systems, which, especially in commercial applications, dwarf the space components in cost and ability to add value to satellite services. Greater R&D investments in terrestrial components would keep the level of technology high enough to deter competitors and would help optimize the space communications system as a whole.

RD&A planning in space communications should recognize the importance of both space and terrestrial components of the satellite system.

COORDINATING MILITARY AND CIVILIAN COMMUNICATIONS SATELLITE RD&A

The similarities between military and civilian communications satellites far outweigh the differences. As Tables 6 to 8 suggest, DOD programs are large and growing. More than half the technologies are applicable to civilian satellites (Posner, 1988). The key differences are that military satellite systems need to work against active threats

TABLE 6 Military Space Communications R&D* (millions of dollars)

	80	81	82	83	84	85	86	87	88
Advanced space communications	26	29	56	36	38	38	30	12	0
DSCS	20	29	52	40	31	26	7	20	22
MILSTAR	0	0	0	107	148	325	337	470	366
FLTSATCOM	1	0	17	24	38	39	19	15	2
Total	7	58	125	207	255	428	393	517	390

*Excluding ground terminal systems.

SOURCE: Quinn, 1988.

TABLE 7 DOD 1986-1987 Advanced Space Communications Projects

- o 7.5, 20, 60 GHz Travelling Wave Tube (TWT)
- o 44 GHz Uplink Nulling Antenna
- o 60 GHz Low Noise Receiver
- o 20 GHz Downlink Active Aperture Antenna
- o Generic Traveling Wave Tubes
- o Hetrodyne Laser Communications Subsystem
- o 44 GHz 25 Watt Solid State Amplifier
- o High Power 44 GHz TWT
- o Advanced Airborne EHF Terminal
- o EHF TT&C Development

SOURCE: Quinn, 1988.

(jamming, ground-station destruction, space defense, etc.) with extremely high probability that connectivity can be maintained among forces in wartime. In peacetime, administrative uses of military satellites are very similar to those of commercial satellites. The Department of Defense, in fact, leases services on commercial satellites. Another derivative difference is that the need for antijam protection (and sometimes low probability of intercept) implies a much higher bandwidth relative to bit rate for military satellites than for commercial satellites. The military technologies of system integrity and bandwidth expansion do not seem transferable to the civil sector in the foreseeable future. Everything else probably is transferable to a significant degree (e.g., microwave component and bus technology), because the frequency regions are not very different and the launch environments are very similar.

TABLE 8 Potential DOD Space Communications R&D Projects

-
- o Active aperture antennas
 - o High speed modulator
 - o High power/high efficiency transmitters (20-100 GHz)
 - o High speed hardened switches
 - o Adaptive nulling receive antennas
 - o Multi-agile beam transmit antennas
 - o Low mass antennas
 - o Hetrodyne laser receivers
 - o High power laser transmitters
 - o Laser multi-beam/agile steering
 - o High speed/low power/hardened digital devices
 - o High data rate laser crosslinks
 - o Anti-jam EHF TT and C
 - o Nuclear power systems
 - o Propagation in nuclear disturbed environment
-

SOURCE: Quinn, 1988.

There is a more specific way that military and civilian communications satellite systems would interact in the event of a national emergency in which both civilian and military communication assets were partly destroyed. The interaction would be via the maintenance of connectivity of national communications so that government authority would be maintained or restored. This interaction implies some degree of joint planning and equipment to allow both commercial and military satellites to be accessed from common or colocated ground terminals.

Because DOD, NASA, and other government satellites share so much in technology and modes of operation, it can be expected that the existence of so many government satellite launches can help produce a more stable and predictable development environment. That environment has been characterized, even before the Challenger disaster, by the great difficulty of conducting technology demonstrations from space, due to lack of coordinated planning, the infrequency of available launches, and the low probability in the near future of a purely commercial development spacecraft.

NASA and DOD, in cooperative efforts, should take the lead within the government to ensure, to the extent practical, applicability to the commercial sector when planning government-funded space communications RD&A, to include flight demonstrations.

References

- Abelson, P. H. 1987. Technology and global industry. *Science* (June 26):1609.
- Aerospace Corp. 1987. Advanced Space Communications Technology Assessment—Air Force Satellite Segment. Report No. TOR-0086A(2418)-1. El Segundo, Calif. September 30.
- AIAA. 1984. Responses to questions from the Subcommittee on Space Science and Applications, Committee on Science and Technology, U.S. House of Representatives. Washington, D.C.: American Institute of Aeronautics and Astronautics, March 6. pp. 6-7.
- American Mobile Satellite Consortium. 1988. Joint Amendment filed before the Federal Communications Commission, Washington, D.C., February 1.
- Anderson, J. W. 1987. Competition in the communications market exposes the payoffs, problems and perils of direct broadcast. *Commercial Space* (Winter):53-59.
- Anderson, R. 1988. Languishing U.S. space effort needs revival of national will. *Financier* (January):41-44.
- Ashford, E. W. 1987. Communication satellite development survey. Paper presented at ESA-ESTEC, Noordwijk, The Netherlands. Published with permission by the American Institute of Aeronautics, Inc., Washington, D.C.
- Aviation Week & Space Technology. May 4, 1987. New Chinese heavy rocket spurs effort to win commercial launch contracts. p. 21.
- Aviation Week & Space Technology. February 15, 1988. Commercial space industry stages major comeback. pp. 51-74.
- Bagwell, J. W. 1984. A System for the Simulation of Evaluation of Satellite Communication Networks. NASA Technical Memorandum 83531. Prepared for the AIAA 10th Communications Satellite Systems Conference.

- Barber, R. J. 1986. Satellites and submarine cables in the Pacific Basin. In Peter J. Booth, ed., *Proceedings of Fibresat 86, International Conference on Satellite and Fibre Optic Communications*. Vancouver, B.C.: Wescon Communications Studies and Research.
- Battelle Columbus Laboratory. 1986. *Outside Users Payload Model*. NASW-3595. Columbus, Ohio: Battelle. p. 169.
- Benedict, H. 1984. *NASA: A Quarter Century of Space Achievement*. Woodland, Tex.: Pioneer Publications.
- Biddle, W. 1987. NASA: What's needed to put it on its feet? *Discover* (January):33-49.
- Braham, H. S. 1988. USA fixed satellite service in the fiber era and the role of operation ACTS. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Brandon, W. T. 1988. Evolution of the Defense Satellite Communications System. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Bransford, L., and S. Douglas. 1985. *Video and Audio Conferencing and Other Special Networks for Social Applications*. Washington, D.C.: Public Service Satellite Consortium.
- Bransford, L., S. Douglas, and D. Widner. 1988. *Communications satellites: User services and benefits*. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Brumley, R. 1988. Department of Commerce perspective on space communications RD&A. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Bulloch, C. 1987a. Satellites save lives. *Space Markets* (Spring):30-35.
- Bulloch, C. 1987b. What happened at WARC-MOB 1987. *Space Markets* (Winter):211.
- Bulloch, C. 1987c. U.S. mobile satellite operators get together at last. *Space Markets* (Winter):212.
- Business Week. June 22, 1987. Research spending is building up to a letdown. pp. 139-157.
- Chase, S., and Langereux, Pierre. 1987. Direct broadcast satellite systems: On the threshold of a dream. *Via Satellite*.
- Clement, D. 1988. A Republican congressional perspective on space communications RD&A. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Cohen, L. R. 1988. Review of Ledyard, 1988. *Proceedings of a Symposium on NASA Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Cohen, L. R., and R. G. Noll. 1988a. The political economy of outer space: government R&D programs for commercializing space. Chapter 6 in *The Technology Pork Barrel*.
- Cohen, L. R., and R. Noll. 1988b. The political economy of NASA's Applications Technology Satellite program. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Communications 21 Corporation. 1985. *World Satellite Systems Scoreboard and Forecast, 1985*. Redondo Beach, Calif. p. 93.

- Communications News. 1987. Special report—Satellite Communications. (March):27-58.
- Cowlan, B., and A. Kavanaugh. 1985. Methods of distribution. In R. L. Hilliard, ed., *Television and Adult Education*. Cambridge, Mass.: Schenkman Books.
- Cuccia, C. L. 1988. International investments in geostationary communications satellites. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Dassler, A. F. 1986. Emerging applications of satellite communications for the 1990s. In Peter J. Booth, ed., *Proceedings of Fibresat 86, International Conference on Satellite and Fibre Optic Communications*. Vancouver, B.C.: Wescon Communications Studies and Research.
- De Sonne, M. L., and M. S. Strong. 1986. *Satellite Issues: 1986*. National Association of Broadcasters, Research and Planning Department. pp. 1-2.
- Demac, D. 1988. Review of Bransford et al. (1988). *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Dickinson, H. 1988. DOD assistance to commercial satellite communications industry. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- The Economist. October 17, 1987. New lines for old. p. 66.
- Edelson, B. I. 1983. *Satellite Communications: Successful Space Business*. Paper presented at IEEE National Telesystems Conference, San Francisco, Calif., November 16.
- Egan, J. J. 1988. Research and development for the communications satellite technology. *Proceedings of a Symposium on Space Communications RD&A*. Washington, D.C.: National Academy Press.
- Evans, R. H. 1978. DSN ground communication facility. *Deep Space Network Progress Report*, Vol. 42-43. Pasadena, Calif.: Jet Propulsion Laboratory. pp. 9-17.
- Filep, R. T. 1988. Opening remarks. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Filep, R. T., et al. 1975. *Communications Satellites and Social Services: Focus on Users and Evaluations*. Los Angeles: University of Southern California Annenberg School of Communications.
- Frieden, R. M., and L. F. Martinez. 1988. Review of Cohen and Noll (1988). *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Frost & Sullivan. 1987. *North American satellite communications market*. New York: Spring.
- Gannes, S. 1988. The good news about U.S. R&D. *Fortune* (February):48-56.
- Grey, J. September 30, 1987. Let private industry revive U.S. space program. *Wall Street Journal*.
- Hampton, J. D. 1986. Intelsat and fiber optics: challenge and opportunity. *Proceedings of Eascon '86*. Washington, D.C.: IEEE. pp. 45-54.
- Hills, A. 1983. Alaska's rural satellite system. *IEEE Spectrum* (July).
- Holmes, W. M., Jr. 1987. Evolving the TDRS system. *Space* 3(2):3.
- Hudson, H. E. 1986. Satellites for development: a retrospective. In Peter J. Booth, ed., *Proceedings of Fibresat 86*,

- International Conference on Satellite and Fibre Optic Communications. Vancouver, B.C.: Wescon Communications Studies and Research. International Resource Development. 1987. Satellite Communications Services and Equipment Markets. New Canaan, Conn.
- Johnston, W. A., Jr. 1980. Technical system tradeoffs. Direct Broadcast Satellite Communications: Proceedings of a Symposium. Space Applications Board and Board on Telecommunications-Computer Applications. Washington, D.C.: National Academy of Sciences.
- Kress, M. A. 1988. Democratic Senate perspective on space communications RD&A. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Ledyard, J. O. 1988. Economic issues in the development of new technology: the role of government in satellite communications RD&A. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Levin, H. J. 1985. Latecomer cost handicap in satellite communications. Telecommunications Policy (June):121-135.
- Levin, H. J. 1988a. Review of Ledyard (1988). Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Levin, H. J. 1988b. Review of Morgan (1988). Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Lopez, R. L. 1987. New life for expendable launchers. Space Markets (Spring):4.
- Los Angeles Times. July 6, 1987. Telstar turns 25: it's a small world after all. IV6.
- Macauley, M. K. 1988. Economic issues in satellite communications R&D. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Maletier, A., and Hinchman, W. 1988. Policy, regulatory, and market environment for satellite communications. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Martin, J. 1978. Communications Satellite Systems. Englewood Cliffs, N.J.: Prentice-Hall. p. 397.
- Matsumoto, K. 1987. Japanese space information system overview. Washington, D.C.: American Institute of Aeronautics and Astronautics. p. 4.
- Miglio, B. 1986. Satellites versus fiber optic cables: the North Atlantic case. Proceedings of Eascon 1986. Washington, D.C.: IEEE. pp. 39-44.
- Morgan, W. L. 1988. Private sector satellite communications investments. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Morra, R. G. 1988. Review of Sackheim et al. (1988). Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Mosbacher, C. J. 1988. R&D funding in U.S. will hit \$132B in 1988. Forecast, Resource Development. January.
- NASA. 1982. OSSA, Office of Communications. Internal Document.
- NASA Headquarters. 1985. Opportunity Notice for a Mobile Satellite Agreement. Office of Space Science and Applications, Washington, D.C., February 25.

- NASA Headquarters. 1987. Payload Flight Assignments, NASA Mixed Fleet, Office of Space Flight, Washington, D.C., October.
- NASA Lewis Research Center. 1986a. Space Communications Program. Industry Briefing. Cleveland, Ohio. July.
- NASA Lewis Research Center. 1986b. An Assessment of the Status and Trends in Satellite Communications 1986-2000. NASA Technical Memorandum 88867. Cleveland, Ohio.
- NASA Space Applications Advisory Committee. 1983. ACTS: Advanced Communications Satellite Program (brochure).
- NASA Space Applications Advisory Committee. 1987. Communication Satellites: Guidelines For a Strategic Plan. Report of the communications subcommittee of the Space Applications Advisory Committee, NASA Advisory Council. Washington, D.C.
- National Commission on Space. 1986. Pioneering the Space Frontier. New York: Bantam Books.
- National Research Council. 1977. Federal Research and Development for Satellite Communications. National Research Council, Space Applications Board. Washington, D.C.: National Academy of Sciences.
- National Research Council. 1987. Space Technology to Meet Future Needs. Aeronautics and Space Engineering Board. Washington, D.C.: National Academy of Sciences.
- National Science Foundation. 1987. Federal R&D Funding by Budget Function FY 86-88. NSF 87-305. Washington, D.C.: U.S. Government Printing Office. p. 95.
- National Technological University. 1987. 1986-1987 Annual Report. Fort Collins, Colo.
- News Report. 1988. Future space programs hinge on new technologies. Washington, D.C.: National Research Council. December-January.
- Organization for Economic Cooperation and Development. 1985. The Space Industry: Trade-Related Issues. Paris. p. 93.
- Osborne, D. 1985. Business in space. The Atlantic Monthly (May).
- Palmer, L. 1988. Space communications: systems and technology. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Park, E. B. 1986. Micro earth station satellite networks and economic development. In Peter J. Booth, ed., Proceedings of Fibresat 86, International Conference on Satellite and Fibre Optic Communications. Vancouver, B.C.: Wescon Communications Studies and Research.
- Park, E. B. 1987. Future perspectives on satellite communication. Telecommunications August:47-48.
- Perkins, P. 1988. A Republican Senate perspective on space communications RD&A. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Pierce, J. R. 1988. Technological considerations in space communications. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Posner, E. C. 1988. Relation between communication satellites and deep-space communication. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Posner, E. C., and R. Stevens. 1984. Deep space communication: past, present, and future. IEEE Communication Magazine 22(5):8-21.

- Posner, E. D., and R. Stevens. 1987. Deep space communication. Pp. 165-185 in *Encyclopedia of Physical Science and Technology*, Vol. 4. New York: Academic Press.
- Pritchard, W. L. 1984. The history and future of commercial satellite communications. *IEEE Communications Magazine* 22(5).
- Profera, C. E. 1988a. Review of Pierce (1988). *Proceedings of Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Profera, C. E. 1988b. Review of Braham (1988). *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Profera, C. E. 1988c. Review of Rosen (1988). *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Public Service Satellite Consortium. 1982. An Overview of the Communications Technology Satellite (CTS) project. Report prepared for NASA. Washington, D.C.
- Quinn, T.P. 1988. DOD perspective on space communications RD&A. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Rappaport, C. S. 1988. Review of Sackheim et al. (1988). *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Ride, S. K. 1987. *Leadership and America's Future in Space: A Report to the Administrator*. NASA, Washington, D.C.
- Robinson, L. M. 1988a. Review of Dickinson (1988). *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Robinson, L. M. 1988b. Review of Brandon (1988). *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Rogers, T. F. 1988. Satellite communications: future potential markets and some related considerations. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Rose, N. L. Economic analysis of communications satellite policies. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Rosen, H. A. 1988. Mobile satellite communications system. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Sackheim, R. L., D. H. Mitchell, and P. J. C. King. 1988. Space launch systems for civil communications satellites. *Proceedings of a Symposium on Space Communications Research and Development*. Washington, D.C.: National Academy Press.
- Satellite Systems Engineering. 1987. *Transponder Supply and Demand Forecast*. SSE/R-86/018. Bethesda, Md. May. p. 150.
- Sawyer, K. 1987. Artificial intelligence: Esprit and RACE—expansion of telecommunications services. *Intermedia* 15(3): 7-9.

- Scherer, L. R. 1988. Review of Sackheim et al. (1988). Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Schnapf, A. 1988. Review of Cohen and Noll (1988). Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Scholz, T. 1987. Special report—Satellites offer telcos a choice. Telephone Engineering Management (May 1):27-58.
- Science. July 24, 1987. Corporations on Campus. p. 353.
- Sergo, J. S. 1988. Review of Braham (1988). Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Shapley, W. 1988. NASA's perspective on space communications RD&A. Proceedings of a Symposium on Space Communications RD&A. Washington, D.C.: National Academy Press.
- Shaw, S. 1987. Hospital satellite network. Business TV (April).
- Shrum, R. 1988. State Department perspective on international aspects of satellite communications RD&A. Proceedings on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Smith, D. D. 1980. Space policy and direct broadcasting via satellite. Direct Broadcast Satellite Communications: Proceedings of a Symposium. Space Applications Board and Board on Telecommunications-Computer Applications. Washington, D.C.: National Academy of Sciences.
- Smith, T. 1988. Review of Sackheim et al. (1988). Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Smith, W. 1988. A Democratic congressional perspective on space communications RD&A. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Smylie, R. E., and L. M. Robinson. 1984. Lessons learned during the first year of the TDRSS. Proceedings of the 10th Annual Communications Satellite Systems Conference. March 19-22. New York: American Institute of Aeronautics and Astronautics.
- Stanford Telecommunications. 1986. TDRS follow-on for the year 2000+. NASA contract no. TB860199. Bethesda, Md. p. 200.
- Stepp, L. S. June 7, 1987. Pope uses space technology to spread an age-old message. Washington Post.
- Sweeney, S. W., and F. S. Zimmerman. Feb. 1988. Communications for disaster recovery. Telecommunications 22(2).
- The White House. 1988. The President's Space Policy and Commercial Space Initiative to Begin the Next Century. Office of the Press Secretary, February.
- Thomsen, C. T. 1981. An integrated telecommunications system. In M. L. Moss, ed., Telecommunications and Productivity. Reading, Mass.: Addison-Wesley Publishing Co.
- TRW. 1986. Space Log 22:54.
- U.S. Agency for International Development. 1975. A Case Study of the ATS-6 Health Education and Telecommunications Projects. Washington, D.C.
- U.S. Congress, House. 1962. Authorizing appropriations to the National Aeronautics and Space Administration. Public Law 87-62. Report No. 96-899. 96th Cong., 2d sess. August 31.

- U.S. Congress, Office of Technology Assessment. 1982. Civilian Space Policy and Applications. Washington, D.C.: U.S. Government Printing Office.
- U.S. Congress, Office of Technology Assessment. 1985. International Cooperation and Competition in Civilian Space Activities. Washington, D.C.: U.S. Government Printing Office.
- U.S. Congress, Office of Technology Assessment. 1987. Commercial Newsgathering from Space. Washington, D.C.: U.S. Government Printing Office. p. 51.
- U.S. News and World Report. February 22, 1988. Losing the right stuff. pp. 44-46.
- Van Nostrand, J. December 28, 1987. Insurance fears shadow commercial space firms. Electronic Engineering Times. p. 14.
- Washington Post. April 22, 1987. DOD and NASA spending on space programs.
- Washington Post. May 20, 1987. U.S. stakes its competitive future on free-market system. p. 81.
- White, R. M. 1988. Welcoming remarks. Proceedings of a Symposium on Space Communications Research and Development. Washington, D.C.: National Academy Press.
- Women's Wear Daily Technology and Operations. January 1987. K-Mart's satellite solution. pp. 12-15, 22.
- Young, E. L. 1983. Communications Satellite Applications: A Brief Overview and Selected Preview. Paper presented at International Aerospace Symposium, Paris, June 1, 1983.

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